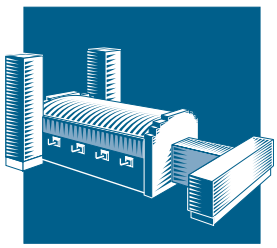
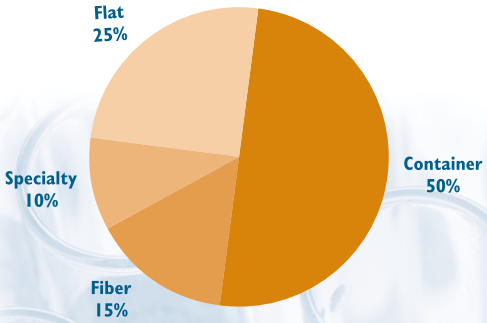
The American glass industry is among the most productive and technologically advanced in the world. It manufactures more than 20 million tons of consumer products each year with an estimated value of $27 billion.



Glass Industry

PROFILE

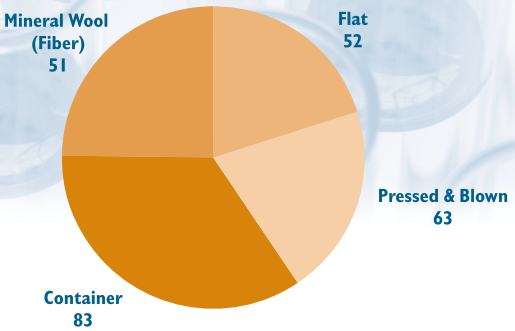
U.S. GLASS PRODUCTION BY SECTOR, 1997



Source: U.S. Dept. of Commerce and industry estimates

Value of Shipments	$27.2 billion
Employment	150,400
Capital Expenditures	$1.93 billion
Net Trade Balance	-$151 million
Net Energy Consumption	249 trillion Btu

ENERGY USE BY SEGMENT, 1994 (trillion Btu)



Source: EIA

MARKETS

Glass is an integral part of the American lifestyle and a staple of the nation's economic success. Its popularity as a material stems from its transparent, recyclable, and nonpermeable qualities.

The U.S. glass industry is comprised of four major segments:

- Container glass
- Fiberglass
- Flat glass
- Specialty glass

COMPETITION

Over the past 25 years, the container and flat glass segments of the industry have become more streamlined—a result of competition from other materials, excess capacity, and rising costs for labor, energy, and environmental compliance. At the same time, the advent of fiber optics and other products have opened up new markets in the specialty glass segment. The industry is now more efficient and closely aligned with customer needs, yet increasingly dependent on improvements in basic processes and product innovations to gain a competitive edge.

Today, the U.S. glass industry's biggest competitive challenges come from (1) foreign glass producers, who typically enjoy lower labor costs and fewer environmental regulations, and (2) producers of alternative materials, such as plastics and aluminum. Meeting these challenges will require careful investment of resources to improve manufacturing processes, make more efficient use of energy and materials, and create new uses for glass.

EMPLOYMENT

Over 150,000 people are employed by the four segments of the U.S. glass industry or by firms manufacturing products of purchased glass. Their average hourly wage is $15.53, which is above the manufacturing average of $13.17 per hour.

ENERGY

Despite the many advantages of glass, glassmaking is energy-intensive. The industry spends over $1.4 billion annually on the energy used in manufacturing. In 1994, glass industry processes consumed about 249 trillion Btu. Approximately 80% of this energy was in the form of natural gas, 17% in the form of electricity, and the remaining 3% in the form of fuel oil and other fuels.

Whereas melting one ton of glass should theoretically require only about 2.2 million Btu, in practice it requires at least twice that much due to various inherent inefficiencies. Overall, energy accounts for about 13% of the total cost of glass products.

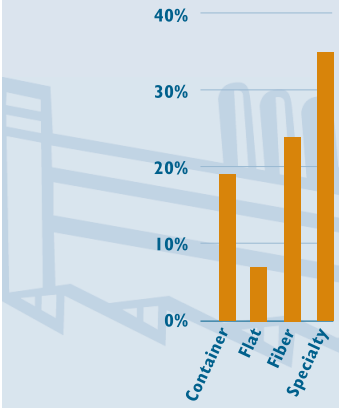
ENVIRONMENT

In comparison with other materials industries, the glass industry has a relatively modest impact on the environment. Its primary materials are in abundant supply and glass products are largely inert and highly recyclable. Nevertheless, the reduction of undesirable emissions and wastes is a central concern of the industry.

Over the past 20 years, increased government regulations have prompted the industry to modify many of its processes and equipment to reduce emissions of NOx, SOx, and particulates. For example, the introduction of oxyfuel firing, in which fuel is burned in a pure oxygen environment, has reduced emissions of critical air pollutants by 50% or more. In particular, oxyfuel furnaces significantly reduce NOx emissions, but they present other operational drawbacks—primarily the high cost of oxygen.

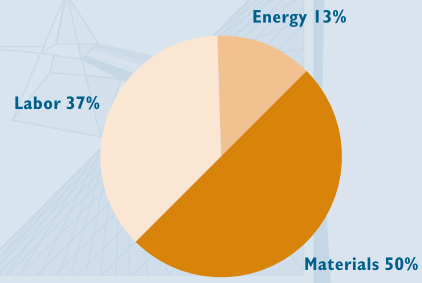
Since recycled glass or cullet can be melted at lower temperatures than raw materials, use of cullet can lower manufacturers' energy costs by $2 to $5 per ton (compared to use of virgin materials), depending on the industry segment. Recycling can also reduce the use of raw materials, decrease CO_2 emissions, and avoid landfilling. However, the level of glass recycling is currently far less than that of other materials, such as steel or aluminum.

OXYFUEL FURNACE MARKET PENETRATION BY INDUSTRY SEGMENT



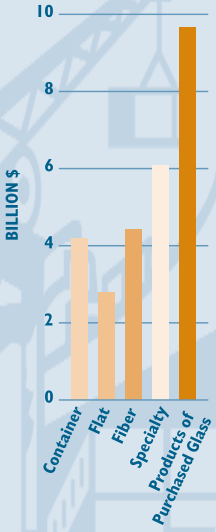
Source: Glass Industry Consulting

COST COMPONENTS OF GLASS PRODUCTS



Source: U.S. Department of Commerce

VALUE OF U.S. GLASS SHIPMENTS (1997) Total - $27.2 billion



Source: U.S. Census Bureau

Industry Vision and Roadmap

GLASS INDUSTRY VISION

In 1996, leaders of the glass industry produced *Glass: A Clear Vision for a Bright Future*, which outlined the industry's long-range vision for maintaining and building its market position. With leadership by a committee of chief executive officers, industry representatives on four subcommittees articulated the desired competitive stance of the industry in 2020 and outlined broad goals in four subareas:

- Production Efficiency
- Energy Efficiency
- Environment
- Innovative Uses for Glass

THE GLASS INDUSTRY ROADMAP WORKSHOP ESTABLISHED INDUSTRY-WIDE PRIORITIES AND PERFORMANCE TARGETS...

SAMPLE PERFORMANCE TARGETS

Production Efficiency	• Reduce capital costs by 25-50% • Improve operating efficiency by 25% • Extend furnace life • Improve process yield and quality while lowering operating costs • Optimize processes through a better understanding of the chemistry and physics involved
Energy Efficiency	• Preheat batch and cullet materials • Develop new melting technology and improve oxyfuel furnaces • Increase yield/decrease rejection rate of product • Improve process throughput
Environment	• Reduce waste and emissions through proactive pollution prevention • Focus on high-value recycling
Innovative Uses for Glass	• Pursue research in areas that will broaden the market for glass products: – Structural applications – High-strength and lightweight glass – Composites – Optical/Photonics – Electrical/Electronic products

GLASS INDUSTRY ROADMAP

Upon completion of the vision, leading representatives of the industry signed a compact with the Secretary of Energy, pledging to work together toward the accomplishment of the defined goals. The industry then took the important next step of organizing a workshop that would lay the groundwork for a glass industry roadmap with performance targets, prioritized research needs, and major milestones.

More than 40 participants from 15 glass companies, labs, universities, and research organizations attended the April 1997 Glass Industry Technology Roadmap Workshop. The Workshop provided an opportunity to verify and validate the initial findings of the sub-committees and gain additional input and insight from a broader cross section of glass producers, research performers, and industry experts. The 1 ½-day workshop was facilitated by OIT and co-sponsored by several glass manufacturers. The participants identified over 130 specific research needs, of which 60 were deemed high priority.

GLASS VISION GOALS

- Reduce unit production costs by at least 20%
- Recycle 100% of available post-consumer glass in localities where consumption > 5 lb/capita
- Reduce by 50% the gap between current process energy use and the theoretical minimum
- Recycle 100% of glass production wastes
- Reduce air and water emissions by at least 20%
- Achieve Six Sigma quality control
- Create innovative products that broaden the marketplace
- Increase supplier and customer partnerships

...AND IDENTIFIED RESEARCH TO ACHIEVE THOSE TARGETS.

NECESSARY RESEARCH

	0-10 Years	Beyond 10 Years
Production Efficiency	• Combined models for glass melting and combustion space modeling • Intelligent control of production and fabrication process • Integrated control strategy	• Longer-lasting materials (nonrefractory) • Corrosion mechanisms of refractory composition
Energy Efficiency	• Models to determine refractory life • Test facility for model verification • Material research for heat-recovery applications	• New/alternative glassmaking technologies • Accurate validated melter models • Nontraditional refining techniques
Environment	• Predictive emissions modeling tools • Cost-effective waste separation and sorting • Improved refractories for melting systems • Efficient, low-cost oxygen production • Integrated control systems to link production with emissions • Durable, high-temperature sensors for flow, temperature, and gas composition	• Instantaneous melting system • New heating mechanisms without noxious emissions • New sensing technologies for in-process measurement of emissions
Innovative Uses for Glass	• Increased understanding/model surface modifications, interactions, chemistry, and reactions of glass interface to other materials • Exploration of microwaves and ultrasonic waves to control shape and other process variables • Optimizing chemical processing for high strength	• Effective sensors for measurement and control of critical parameters

Team & Partnership Activities

"The GMIC provides a unified voice for the glass industry, facilitating cooperation and leveraging research resources to address issues of common concern."

— Walter Scott, PPG Industries

Priorities established at the Glass Industry Roadmap Workshop guide the OIT Glass Team's R&D solicitations and project awards. The selected R&D projects help to attain specific performance targets set by the glass industry in its vision statement.

OIT's Glass Team also sponsors the annual *Glass Project Review*, in which technical managers from glass companies review the progress of ongoing glass R&D projects and advise the principal investigators on technical direction. These reviews have been highly successful and have attracted broad industry participation.

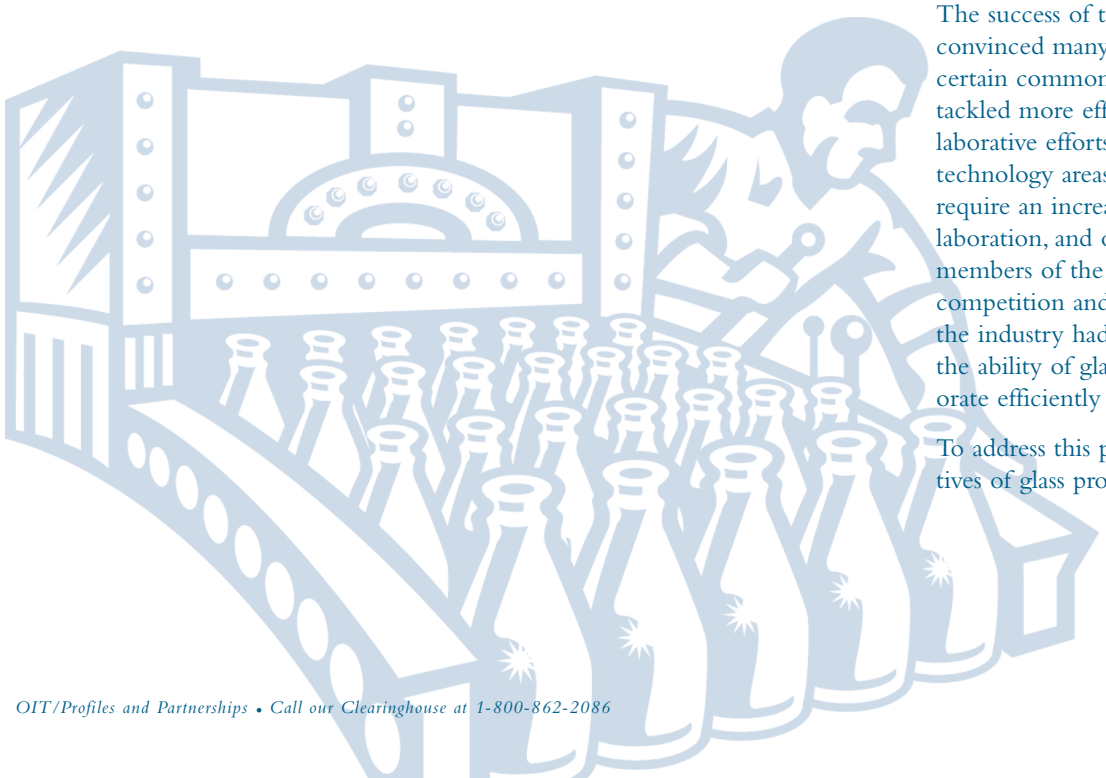
By virtue of its diverse contacts with a wide range of industry groups, the Glass Team is in a good position to spot potentially useful linkages. In September 1998, for example, the team and the U.S. Advanced Ceramics Association (USACA) jointly sponsored a workshop that brought together representatives of the glass and ceramics industries to begin identifying ways in which ceramic materials may help to solve some of the problems facing glass producers. This initial, exploratory venture focused on refractories, molds, and shielding for sensors as the most likely areas for further investigation.

In addition to cost-sharing selected projects that specifically address the glass industry's top technology needs, OIT awards cost-shared funding for projects that enable or support cleaner and more energy-efficient manufacturing in a wide range of U.S. industries, including glass. OIT maintains active programs in combustion, sensors and controls, and advanced industrial materials. Several projects that started in these areas have been applied to the glass industry. Examples of such projects include oxyfuel firing from the combustion area and a tough, thermal shock-resistant material for sensors from the advanced materials area. The OIT Glass Team is now supporting a number of follow-on projects related to glass applications of these technologies.

A CENTRAL ORGANIZING COUNCIL FOR THE INDUSTRY

The success of the roadmap workshop convinced many industry leaders that certain common problems could be tackled more effectively through collaborative efforts. Pursuit of the priority technology areas, however, would require an increase in participation, collaboration, and organization among all members of the glass community. The competition and segmentation within the industry had historically hindered the ability of glass producers to collaborate efficiently on technology R&D.

To address this problem, key representatives of glass producers met in Novem-



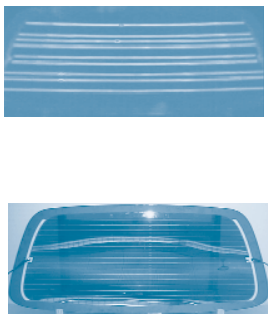
ber 1997. They expressed the need to create an umbrella organization to serve as a focal point for technology collaboration, especially with respect to government agencies and laboratories. This led to the creation of the Glass Manufacturing Industry Council (GMIC) to coordinate pre-competitive R&D for glass manufacturers under the auspices of the American Ceramic Society. The GMIC is dedicated to promoting the interests and growth of the entire U.S. glass industry through cooperation in the areas of technology, productivity, and the environment. On behalf of the glass industry, the GMIC renewed the compact to work collaboratively with DOE in a signing ceremony in February 1999.

REPRESENTATIVE GLASS-RELATED PROJECTS IN OIT'S PORTFOLIO

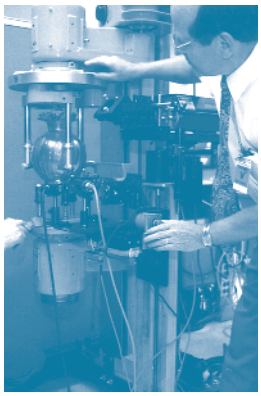
	PRODUCTION EFFICIENCY	ENERGY EFFICIENCY	ENVIRONMENTAL	INNOVATIVE USES FOR GLASS
Glass Team				
•Advanced Process Control System for Glass Production	●	●		
•Automated Infrared-based Inspection System for Automotive Heated Backlights	●	●	●	
•Auto Glass Process Control		●	●	
•Enhanced Cutting and Finishing of Handglass Using a Carbon Dioxide Laser	●			●
•Glass Furnace Combustion and Melting User Research Facility	●	●		
•High-Luminosity, Low-NOx Burner	●	●	●	
•Improved Refractories for Glass	●	●	●	
•Integrated Batch and Cullet Preheater System	●	●	●	
•Integrated Ion-Exchange Systems for High-Strength Glass Products		●		●
•Modeling of Glass Making Processes	●			
•Molybdenum Disilicide Composites for Glass Processing Sensors	●	●	●	●
•On-line Chemical Vapor Deposition of Coatings on Float Glass	●	●		
Inventions & Innovation				
•Producing Glass Fiber	●	●		●
•Rotary Electric Glass Furnace	●	●		●
•Single-Chip Color Sensor for Glass Recycling and Quality Control	●		●	
Sensors and Controls				
•Sensor Fusion for Intelligent Process Control	●	●		

See "Selected Glass Portfolio Highlights" on the next two pages for additional information

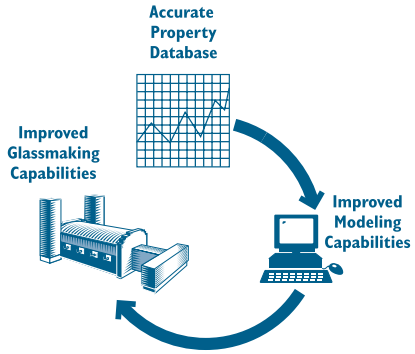
Selected Glass Portfolio Highlights



Infrared imaging system will eliminate defects and improve productivity.

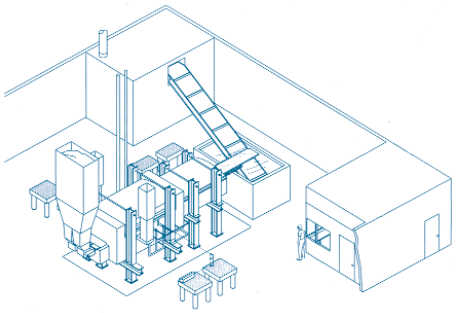


Laser-cutting glass while it is still hot will produce a finished edge.

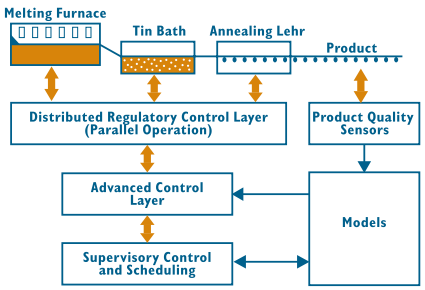


Property database will contribute to more efficient glassmaking processes for the entire industry.

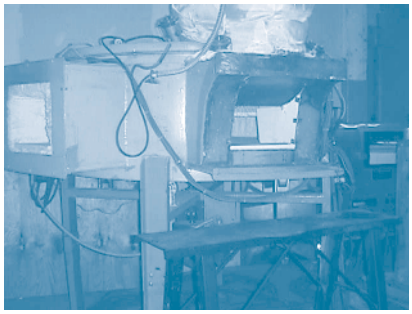
AREA	ENVIRONMENTAL	INNOVATIVE USES	PRODUCTION EFFICIENCY
PROJECT	**Automated Infrared-based Inspection System for Automotive Heated Backlights**	**Enhanced Cutting and Finishing of Handglass Using a Carbon Dioxide Laser**	**Modeling of Glass Making Processes**
DESCRIPTION	A new, automated inspection system can detect defective automotive backlights (the rear window with a defroster circuit) on-line during the manufacturing process. The system uses infrared imaging techniques to obtain an image of the heated backlight and analyzes it to spot defects such as hot spots or broken lines. Currently, the backlights are inspected manually or during infrequent tests; this new technology will reduce end waste. • Reduces production and environmental waste at assembly station • Improves the competitive position of the U.S. glass industry	Laser-enhanced cutting and finishing methods will dramatically decrease waste and improve productivity in the manufacture of handblown glass. Researchers will develop a bench-scale prototype system using a sensor-controlled, moderate-power, carbon dioxide laser to precision-cut the glass and produce a finished edge. A major component of the work will involve development of the operating parameters to make the system feasible for use in handglass factories. • Minimizes waste and defects • Improves product quality • Reduces material costs: current losses can be as high as 80% in some product lines or 40% total scrap • Improves production efficiency and decreases overall energy use • Reduces worker hazards, such as exposure to sharp edges and broken fragments	The Center for Glass Research is developing a database of all the important, physical properties of glass that will allow researchers to develop accurate computer codes for glass melting, refining, and homogenizing processes. The resulting modeling capabilities will improve manufacturing processes to consistently and economically produce high-quality glass. • Improves production efficiency • Increases energy efficiency • Reduces production costs • Reduces waste and hazardous emissions
PARTNERS	Georgia Institute of Technology Ford Motor Company/Visteon Glass Systems	The Federal Energy Technology Center Fenton Art Glass Pilgrim Glass West Virginia University	The Center for Glass Research



A central research facility will facilitate development of more efficient glass furnaces.



Distributed and hierarchical control of flat glass production



New rotary electric glass furnace

ENERGY EFFICIENCY

Glass Furnace Combustion and Melting User Research Facility

All segments of the glass industry concur that the industry needs a central research facility to explore technology that can improve combustion and furnace efficiency. The goal of the project is to design and build a state-of-the-art user facility for developing improved monitoring instrumentation for batch reactions, melt properties, and combustion space conditions in glass furnaces in order to improve production efficiency.

- Benefits manufacturers in all industry segments
- Improves production and energy efficiency for combustion and melting processes

Sandia National Laboratories
Visteon Glass Systems

PRODUCTION EFFICIENCY

Sensor Fusion for Intelligent Process Control

Researchers are developing a fusion strategy for linking the sensors and expert control elements of production furnaces using an on-line control system that will improve energy efficiency while minimizing a variety of product defects. Although its target use is in flat glass production, this low-cost, adaptable system can be used in any facility that transforms raw materials into finished products using multistep processes with nonlinear behavior and slow output response to changing conditions.

- Reduces energy use in glass melting furnaces by 5%
- Increases flat glass production yield by 5%
- Reduces emissions of CO_2 and SO_2

Sandia National Laboratories
University of Utah
Visteon Automotive Systems

ENERGY EFFICIENCY

Rotary Electric Glass Furnace

Glass optical blanks manufactured for the photonics industry are generally molded in conventional gas-fired furnaces, which exhaust about 93% of the energy used. A new rotary electric furnace has no exhaust stack and, therefore, no waste heat. Additionally, electric heating can be accurately controlled by computer, improving the efficiency, capacity, and operating costs of the new furnaces.

- Increases energy efficiency of molding glass optical blanks at least threefold
- Improves product throughput, quality, and turnaround time
- Doubles production capacity without additional investment
- Reduces labor costs

Advanced Glass Industries

For more information on OIT's Glass Portfolio, visit www.oit.doe.gov/glass